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14. ABSTRACT
Report developed under Topic #A12a-T013, contract W911NF-13-C-005. NCSU played a critical role in casting concrete blocks with compressive strengths ranging from 7.6 ksi to 26.8 ksi after curing in the CFL environmental chamber. NLAD was able to demonstrate the ability of the NLA RECON™ to detect wall thickness and estimate concrete compressive strength within the accuracy required by the U.S. Army, locate steel reinforcing bars, and identify the presence of steel fiber reinforcement. The thickness of all sides of each concrete block was measured

15. SUBJECT TERMS
Ultrasonic Pulse Velocity (UPV), Impact-Echo, Ultrasonic Pulse-Echo, Ultrasonic Attenuation, STTR Report

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Sixth Month Progress Report - Final Report

ABSTRACT

Report developed under Topic #A12a-T013, contract W911NF-13-C-005. NCSU played a critical role in casting concrete blocks with compressive strengths ranging from 7.6 ksi to 26.8 ksi after curing in the CFL environmental chamber. NLAD was able to demonstrate the ability of the NLA RECON™ to detect wall thickness and estimate concrete compressive strength within the accuracy required by the U.S. Army, locate steel reinforcing bars, and identify the presence of steel fiber reinforcement. The thickness of all sides of each concrete block was measured using the P-wave velocity obtained from the pitch-catch method of ultrasonic testing in conjunction with the resonance frequency. All results were within the specified tolerance of ±1 ft. The compressive strength of the concrete blocks was measured by measuring the P-wave and S-wave time of travel with the pitch-catch method of ultrasonic testing. All results were within the specified tolerance of ±3 ksi. The presence and approximate location of internal rebar was detected successfully using the pitch-catch method. When testing over a bar, the returned signal would increase greatly, indicating a strong reflection had occurred. Metallic fibers were detected magnetically. Synthetic fiber was not detected; however, higher frequency transducers might enable detection.

Enter List of papers submitted or published that acknowledge ARO support from the start of the project to the date of this printing. List the papers, including journal references, in the following categories:

(a) Papers published in peer-reviewed journals (N/A for none)

Received Paper

TOTAL:

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(b) Papers published in non-peer-reviewed journals (N/A for none)

Received Paper

TOTAL:

Number of Papers published in non peer-reviewed journals:

(c) Presentations

Number of Presentations: 0.00

Non Peer-Reviewed Conference Proceeding publications (other than abstracts):

Received Paper

TOTAL:

Number of Non Peer-Reviewed Conference Proceeding publications (other than abstracts):

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(d) Manuscripts

Received Paper

TOTAL:

Number of Manuscripts:

Books

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TOTAL:

Patents Submitted

Patents Awarded

Awards

Graduate Students

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Names of Post Doctorates

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FTE Equivalent:
Total Number:

Names of Faculty Supported

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Total Number:

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Student Metrics

This section only applies to graduating undergraduates supported by this agreement in this reporting period

The number of undergraduates funded by this agreement who graduated during this period:	0.00
The number of undergraduates funded by this agreement who graduated during this period with a degree in science, mathematics, engineering, or technology fields:......	0.00
The number of undergraduates funded by your agreement who graduated during this period and will continue to pursue a graduate or Ph.D. degree in science, mathematics, engineering, or technology fields:......	0.00
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Names of Personnel receiving masters degrees

NAME

Total Number:

Names of personnel receiving PHDs

NAME

Total Number:

Names of other research staff

NAME	PERCENT_SUPPORTED

FTE Equivalent:

Total Number:

Sub Contractors (DD882)

1 a. North Carolina State University

1 b. Research Administration

2701 Sullivan Drive, Suite 240

Raleigh NC 276957514

Sub Contractor Numbers (c):

Patent Clause Number (d-1):

Patent Date (d-2):

Work Description (e):

Sub Contract Award Date (f-1):

Sub Contract Est Completion Date(f-2):

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Raleigh NC 276957214

Sub Contractor Numbers (c):

Patent Clause Number (d-1):

Patent Date (d-2):

Work Description (e):

Sub Contract Award Date (f-1):

Sub Contract Est Completion Date(f-2):

Inventions (DD882)

Scientific Progress

Technology Transfer

Sixth Month Progress Report – Final Report

1. Contract and Proposal Number:	**W911NF-13-C-005, A 12A-013-0200**
2. Contractor's name and address:	**NLA DIAGNOSTICS LLC**
	2118 Water Ridge Parkway, Suite 275
	Charlotte, NC 28217-5525
3. Title of the project:	**Nondestructive Concrete Characterization System**
4. Contract performance period:	**14 November 2012 through 14 May 2013**
5. Total contract amount:	**$99,968.00**
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14. ABSTRACT Report developed under Topic #A12a-T013, contract W911NF-13-C-005. NCSU played a critical role in casting concrete blocks with compressive strengths ranging from 7.6 ksi to 26.8 ksi after curing in the CFL environmental chamber. NLAD was able to demonstrate the ability of the NLA RECON™ to detect wall thickness and estimate concrete compressive strength within the accuracy required by the U.S. Army, locate steel reinforcing bars, and identify the presence of steel fiber reinforcement. The thickness of all sides of each concrete block was measured using the P-wave velocity obtained from the pitch-catch method of ultrasonic testing in conjunction with the resonance frequency. All results were within the specified tolerance of ±1 ft. The compressive strength of the concrete blocks was measured by measuring the P-wave and S-wave time of travel with the pitch-catch method of ultrasonic testing. All results were within the specified tolerance of ±3 ksi. The presence and approximate location of internal rebar was detected successfully using the pitch-catch method. When testing over a bar, the returned signal would increase greatly, indicating a strong reflection had occurred. Metallic fibers were detected magnetically. Synthetic fiber was not detected; however, higher frequency transducers might enable detection.			
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Sixth Month Progress Report – Final Report

Table of Content

Sixth Month Progress Report – Final Report

1 Scope of Work

NLA Diagnostics (NLAD) and North Carolina State University (NCSU) have teamed up to meet or exceed the following objectives on this STTR project:

1. Detect concrete wall thickness up to 6 ft with a tolerance of ±1 ft.
2. Estimate compressive strength of concrete ranging from 3 ksi to 30 ksi with a tolerance of ±3 ksi.
3. Detect the presence of fiber reinforcement.
4. Locate and detect the presence and density (e.g. spacing) of metallic objects (such as steel reinforcing bars) within 1 ft from the concrete surface.

2 Government Documents

W911NF-13-C-0005	Contract W911NF-13-C-0005 - NLA (STTR Phase I)
FAR 16.202	Federal Acquisition Regulation 16.202
A12A-013-0200	Department of Defense Small Business Technology Transfer (STTR) proposal # A12A-013-0200, 5 November 2012
62523-CH-ST1	ARO Proposal No. 62523-CH-ST1 “Nondestructive Concrete Characterization:
ARO Form 18	U.S. Army Research Laboratory – Army Research Office Reporting Instructions, May 2011
DOD FY2012.A STTR	Solicitation Number DOD FY2012.A STTR
SF 298	Report Documentation Page
DD Form 882	Report of Inventions and Subcontracts

In the event of an inconsistency between the provisions of the Contract W911NF-13-C-0005 - NLA (STTR Phase I) and the Contractor’s Proposal (A12A-013-0200) , the inconsistency shall be resolved by giving precedence in the following order: (a) the contract (W911NF-13-C-0005), (b) other attachments or modifications to the contract, and (c) the technical proposal (A12A-013-0200).

3 Test Methods

NLAD used the NLA RECON™ to address each of the objectives using the following test methods as shown in the STTR test matrix in Figure 1.

1. Impact-echo and pulse-echo was used to estimate the wall thickness.
2. Ultrasonic pulse velocity (UPV) and ultrasonic attenuation was used to estimate compressive strength.
3. Impact-echo, pulse-echo, and ultrasonic attenuation was used to detect the presence of fiber reinforcement.
4. Pulse-echo and UPV was used to detect the presence and location of metal objects such as steel bar reinforcement.
5. Pulse-echo and UPV was used to detect the presence of a steel substrate against the back wall of concrete.

STTR Test Matrix		**Test Objective**				
		Thickness	**Strength**	**Fiber Detection**	**Rebar Detection**	**Metallic Substrate Detection**
Test Method	Impact Echo					
	Pulse Echo					
	Ultrasonic Pulse Velocity					
	Ultrasonic Attenuation					
Material	6 ksi concrete					
	12 ksi concrete					
	18 ksi concrete					
	Ultra-High Performance Concrete (UHPC)					
	6 ksi fiber reinforced concrete					
	6 ksi steel reinforced concrete					

Figure 1. STTR Test Matrix

4 Test Equipment

The NLA RECON™ operates in different modes of operation including, but not limited to ultrasonic pulse velocity (UPV), impact-echo, ultrasonic pulse-echo, and ultrasonic attenuation to extract material and structural information from the target structure and perform rapid analysis. Estimation of the charge for explosion can also be integrated into this equipment as post processing.

5 Results of the Phase I Work

5.1 Phase I Technical Objectives

During Phase I testing, NLA Diagnostics LLC (NLAD) and North Carolina State University (NCSU) have teamed up to meet or exceed the following objectives on this STTR project:

1. Detect concrete wall thickness up to 6 ft with a tolerance of ±1 ft.
2. Estimate compressive strength of concrete ranging from 3 ksi to 30 ksi with a tolerance of ±3 ksi.
3. Detect the presence of fiber reinforcement.
4. Locate and detect the presence and density (e.g. spacing) of metallic objects (such as steel reinforcing bars) within 1 ft from the concrete surface.

A limited study on the interaction of different parameters (such as strength and wall thickness) was also performed. In addition to demonstrating the capabilities of the NLA RECON™, minimal modification to the current algorithms and hardware were performed to adapt this equipment for the specific applications of the U.S. Army.

5.2 Research Conducted

5.2.1 NCSU Research Conducted

In Phase I NCSU was primarily responsible for the design, manufacture, and handling of large-scale concrete blocks at the Constructed Facilities Laboratory (CFL). The blocks were designed to enable NLAD to test the ability of the NLA RECON™ system to detect concrete thickness, steel substrate (including steel reinforcing bars and steel plate), and fiber reinforcement (including steel and synthetic structural

fibers). NCSU played a critical role in acquiring conventional concrete with compressive strengths ranging from 7.6 ksi to 14.9 ksi in collaboration with a local ready-mix concrete supplier. Further, NCSU was able to acquire ultra-high performance concrete (UHPC) materials from a commercial supplier to cast a block that achieved a compressive strength of 26.8 ksi after curing in the CFL environmental chamber. At the time of non-destructive evaluation (NDE) testing by NLAD, NCSU also undertook destructive testing of small-scale cylinder and beam specimens cast from the same concrete as the blocks to establish the mechanical properties of the concrete material. The destructive tests were undertaken according to the relevant ASTM standards using calibrated testing equipment and instrumentation.

5.2.2 NLAD Research Conducted

In Phase I NLAD was able to demonstrate the ability of the NLA RECON™ to detect wall thickness and estimate concrete compressive strength within the accuracy required by the Army, locate steel reinforcing bars, and identify the presence of steel fiber reinforcement. In addition, NLAD was able to demonstrate the capabilities of the NLA RECON™ with minimal modification to the current algorithms and hardware to adapt this equipment for the specific applications of the U.S. Army.

The research conducted includes: the measurement of the P-wave and S-wave velocities using the pitch-catch method of ultrasonic testing; the measurement of the resonance frequency using the impact echo method for walls up to 6 ft thick and cast with concrete of compressive strength ranging from 7.6 to 26.8 ksi, including synthetic and steel fiber reinforcement; the location of steel reinforcing bar; and the identification of steel fiber reinforcement.

The testing was conducted in the CFL at NCSU. The concrete test blocks and NLAD test equipment are shown in Figure 2.

Figure 2: Concrete Test Blocks with Test Equipment in the CFL at NCSU

5.3 Findings and Results

NCSU prepared all the specimen formwork, small beam molds, and cylinder molds in Phase I. The large blocks were cast for Non Destructive Testing (NDT) along with the cylinders and small beams for destructive testing with the following target concrete mixes: 6 ksi, 6 ksi fiber reinforced, 12 ksi, 18 ksi, and 30 ksi ultra-high performance concrete (UHPC). The 6 ksi fiber reinforced concrete block was cast with FIBERMESH® 650, an engineered graded macro-synthetic structural fiber. The UHPC concrete block was prepared with steel fiber reinforcement as per the manufacturer's specifications.

5.3.1 Destructive Tests

NCSU performed the destructive testing in accordance with the following standards: ASTM C39 for compressive strength, ASTM C469 for modulus of elasticity; ASTM C496 for splitting tensile strength, ASTM C642 for concrete density, and ASTM C78 for modulus of rupture. The recorded test results are shown in Table 1:

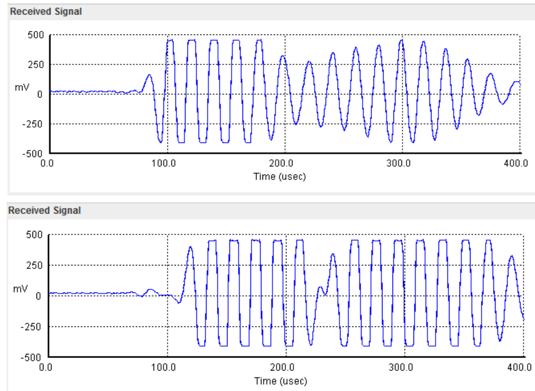
Table 1: Final Destructive Concrete Material Properties

Concrete Material	Compressive Strength (ksi)	Density (g/cm^3) [pcf]	Modulus of Rupture (psi)	Splitting Tensile Strength (psi)	Tensile Strength / Compressive Strength
6 ksi	7.86	2.34 [146]	693	656	8%
6 ksi + fiber	7.60	2.34 [146]	652	656	9%
12 ksi	12.18	2.26 [141]	652	639	5%
18 ksi	14.90	2.48 [155]	767	788	5%
UHPC	26.80	2.57 [160]	2728	2557	10%

As expected, the ratio of Tensile Strength to Compressive Strength varies from 5% to 10% depending on the concrete mix. The density of the concrete cylinders varied from 2.26 g/cm^3 to 2.57 g/cm^3.

5.3.2 Compressive Strength Tests

Using the pitch-catch method of ultrasonic testing, NLAD was able to differentiate the compressive strength of these concrete blocks within a tolerance of ±3 ksi by measuring the P-wave and S-wave time of travel. The P-wave transducer required an input signal level of 592 Volts peak-to-peak (Vpp) in order to obtain a shorter rise time. The S-wave transducer required an input signal level of 42 Vpp in order to minimize the effect of the P-wave, which is inherent to the S-wave transducers. The start-time for wave instigation was determined by setting a threshold above the background values. For the P-wave received signal, the threshold was set above the background noise level to record the P-wave time of travel. For the S-wave received signal, the threshold was set above the P-wave level to record the S-wave time of travel. These settings can be performed automatically via an algorithm to be developed in Phase II. The received signals, as shown in Figure 3, were also saturated to reduce variability.



P-wave

S-wave

Figure 3: Typical P-wave and S-wave Received Signal

The recorded test results are shown in Table 2 and Table 3:

Table 2: P-wave and S-wave Velocities

Concrete Material	Receiver Type	Time of Travel				Δt	Velocity	Systematic Error	P-wave to S-wave Ratio
		(in)	(µsec)	(in)	(µsec)	(µsec)	(m/s)	(m/s)	
6 ksi	P-wave	6	46.4	9	66.8	20.4	3735	±36	59%
	S-wave	18	221.2	21	255.6	34.4	2215	±13	
6 ksi + fiber	P-wave	6	46.8	9	68.4	21.6	3528	±32	68%
	S-wave	18	218.8	21	250.4	31.6	2411	±15	
12 ksi	P-wave	6	47.6	9	66.8	19.2	3969	±41	66%
	S-wave	18	220.8	21	250	29.2	2610	±18	
18 ksi	P-wave	6	41.6	9	60.4	18.8	4053	±43	64%
	S-wave	18	206.4	21	236	29.6	2574	±17	
UHPC	P-wave	6	35.2	9	50.4	15.2	5013	±65	54%
	S-wave	18	163.2	21	191.2	28.0	2721	±19	

Table 3: Compressive Strength Test Results

Concrete Material	Receiver Type	Velocity (m/s)	Young's Modulus (MPa)	Calculated Strength (psi)	Actual Strength (psi)	Difference (psi)	Systematic Error (psi)
6 ksi	P-wave	3735	28651	5778	7860	-2082	±243
	S-wave	2215					
6 ksi + fiber	P-wave	3528	29331	6199	7600	-1401	±311
	S-wave	2411					
12 ksi	P-wave	3969	36217	11671	12180	-509	±612
	S-wave	2610					
18 ksi	P-wave	4053	36591	12036	14900	-2864	±607
	S-wave	2574					
UHPC	P-wave	5013	45439	23048	25800	-2752	±1146
	S-wave	2721					

NLAD used an average of 2.38 g/cm^3 for the densities in calculating the above values for Young's Modulus. The S-wave velocity was found to be on average 62.2% of the P-wave velocity. NLAD also found that the concrete surface velocity changed from one location and orientation to another due to the non-homogenous nature of concrete, as expected. However, NLAD has addressed this issue by placing all transducers along the same axis. In this manner, the surface velocities of concrete can be determined for specific locations with minimal variation caused by the non-homogeneity of the concrete. Not only was the calculated compressive strength within the ±3 ksi tolerance, but the P-wave velocity difference between conventional concrete and UHPC was at least 1000 m/s. This increase in velocity is most likely caused by the steel fiber in the UHPC mix.

NLAD used a 1 ft cylindrical rod made of Polymethylinethacrylate (PMMA, or Plexiglas) as a calibration standard to verify the accuracy of this test method on a homogeneous material. The expected Poisson's Ratio (v) is between 0.35 and 0.40. The measured longitudinal and shear wave velocities were 2717 and 1236 m/s, which provides a calculated Poisson's ratio (v) of 0.37, as shown in Table 4.

Table 4: PMMA Calibration Rod Test Results

Test Method	Receiver Type	Time of Travel (μsec)	Calibration (μsec)	Δt (μsec)	Distance (in)	Velocity (m/s)	Poisson Ratio
Through Transmission	P-wave	124	11.8	112.2	12	2717	0.37
	S-wave	258.4	11.8	246.6	12	1236	

The Ultrasonic Pulse Velocity (UPV) test method in the pitch-catch configuration determined the compressive strength of the concrete specimens within the tolerance set by the U.S. Army. When performing this test method, the transducers must be aligned with each other and tested along the same axis to minimize the variability in velocity caused by the non-homogeneous nature of concrete. The P-wave transducers use square piezoelectric elements which must be aligned with each other so that the time of travel is the same.

The S-wave transducer transmits an S-wave and a P-wave. The P-wave arrives first (higher velocity) at a lower amplitude, then the S-wave arrives (lower velocity) at a higher amplitude. Turning either S-wave transducer 90-degrees will position them out of phase, which is useful to determine the location of the S-wave arrival. If the transducers are out of phase, the P-wave is combined with the S-wave amplitude. However, when the transducers are in phase, the S-wave start time can be more easily determined.

There was a direct relationship between signal voltage and the physical pressure applied to the transducers when using the dry pads; however this also happened with the gel. Enough pressure must be applied to the transducers in order to obtain proper coupling between the transducer and the concrete surface. For the final product, a range of signal voltages will be automatically transmitted to adjust for the amount of pressure and the difference in required voltage for the P-wave and S-wave. The transducers will also be spring loaded to accommodate any variations on the concrete surface. Once pressure is applied, the variability of signal level from the P-wave transducer decreased over time, however, the S-wave transducer worked best when pressure was applied, released, and then applied again. This enabled the dry pad to settle into the surface texture.

The acoustic attenuation method was found to be impractical for field testing as the pressure on the transducers affected the received signal strength too much for a reliable concrete strength reading using this method. In addition, the surface wave was much greater than the reflected wave making the reflected attenuation difficult to determine.

Impact echo testing should not be used to determine the wave velocity in concrete as there is a large variance in the location of impacts (even with 0.5 in tolerances). Also, the impact echo velocities were found to be about half of the velocity than when using the P-wave transducers.

5.3.3 Thickness Tests

The velocity obtained from the impact echo method was found to only be approximately half of the P-wave velocity, which is required for thickness measurement. Thus, the P-wave velocity obtained from the pitch-catch method of ultrasonic testing was used to calculate the thickness in conjunction with the resonance frequency from the impact echo method. Using this test combination, NLAD was able to calculate the thickness of all sides of each concrete block within a tolerance of ±1 ft. The recorded test results are shown in Table 5.

Table 5: Thickness Test Results

Concrete Material	P-wave Velocity (m/s)	Resonance Frequency (kHz)	Calculated Thickness (ft)	Actual Thickness (ft)	Difference (ft)	Systematic Error (ft)
6 ksi	3852	3.30	1.91	2	-0.09	±0.030
		2.35	2.69	3	-0.31	±0.054
		1.05	6.02	6	+0.02	±0.240
6 ksi + fiber	4020	3.25	2.03	2	+0.03	±0.033
		2.35	2.81	3	-0.19	±0.057
		1.05	6.28	6	+0.28	±0.251
12 ksi	3799	3.45	1.81	2	-0.19	±0.027
		2.35	2.65	3	-0.35	±0.052
		1.05	5.93	6	-0.07	±0.236
18 ksi	4304	3.45	2.05	2	+0.05	±0.032
		2.50	2.82	3	-0.18	±0.055
		1.10	6.42	6	+0.42	±0.246
UHPC	4672	4.75	1.61	1	+0.61	±0.025
		4.00	1.92	2	-0.08	±0.032
		3.85	1.99	1.5	+0.49	±0.034

When testing for thickness using the impact echo test method, the Tektronix TDS 2002B oscilloscope was used for high resolution in conjunction with the 1.75 in steel ball (impact head) and broadband transducer receiver. Testing showed that when impacting on the widest side (6 ft width), it was easy to find the frequency corresponding to the correct depth as it was the first high amplitude frequency peak. However, when testing on the 2 ft and 3 ft wide sides, the frequency peak corresponding to the 6 ft depth was still visible. Since testing was performed on discrete concrete blocks, the frequency corresponding to the thickest part of the block was always visible. When testing a wall in practical application, the frequency corresponding to the depth should be the most dominant resonant peak, as the other edges of the wall will be much further away.

5.3.4 Fiber Detection

A typical maximum theoretical compressive strength of a conventional concrete mix (without fiber reinforcement) is in the order of 18 ksi, and depends significantly on the quality of the available

constituent materials. Thus, for high performance concretes with compressive strengths generally above 18 ksi, the presence of fibers is very likely.

NLAD was able to detect steel fibers used in the UHPC with a simple refrigerator magnet. NLAD attempted to detect the synthetic fibers in the target 6 ksi concrete using non-linear harmonic generation, impact echo, and ultrasonic pitch-catch test methods with no success. However, NLAD believes that synthetic fibers may be detectable with higher frequency transducers. NLAD only has lower frequency transducers available at this time.

5.3.5 Rebar Detection

Automatic gain control (AGC) is a process by which the amplitude is maintained at a fixed level throughout. NLAD determined that AGC was not suitable for rebar detection because it can remove the characteristics that are needed, such as the relative amplitudes between signals. With the AGC turned off, the pitch-catch method was successful in determining the location of rebar. When testing over the rebar, the received signal would increase greatly, which indicated a strong reflection had occurred. The density (spacing) of rebar can also be detected in this manner when an array is utilized.

As shown in Figure 4, the rebar is detected when the signal level saturated (above 850 Vpp). A second reflection of the rebar can also be seen in lines I through K of Figure 4 allowing detection of the rebar location. While there appears to be an increase in signal level around lines B and C, these signal levels were at least 250 Vpp less that those found around I through K. This testing was performed on a target 3 ksi 1'x1'x1' concrete block with a single rebar centrally located within the block, as shown in Figure 5. The pulse amplifier was set at 850 Vpp and the P-wave transducers were positioned 6 in apart and moved at half inch increments.

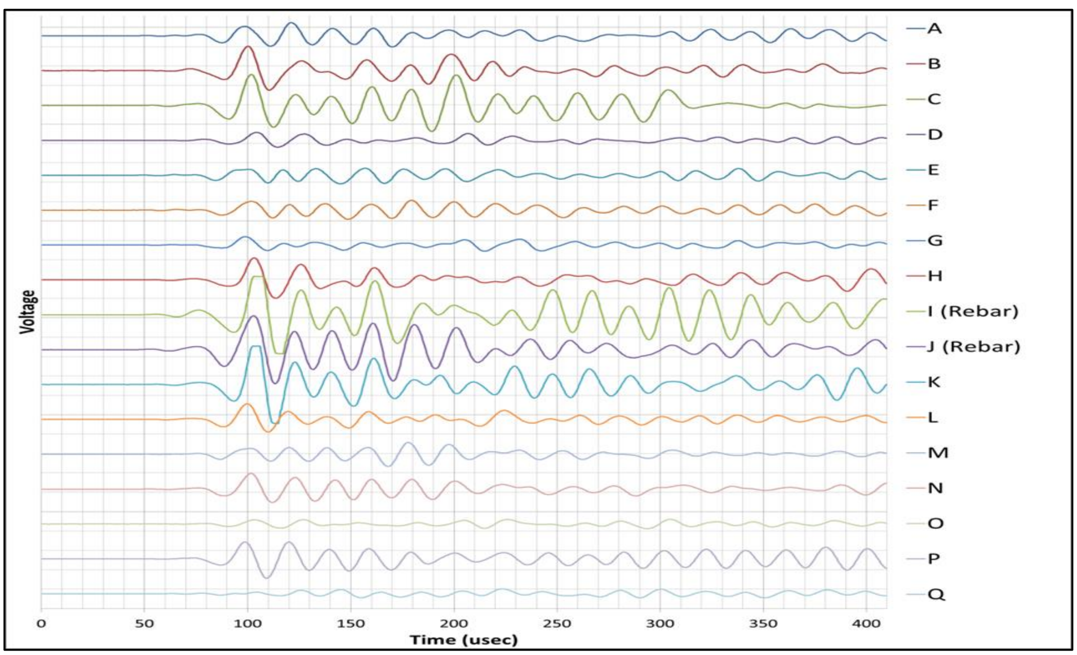


Figure 4: Rebar Detection

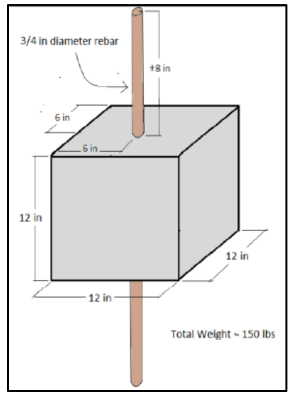


Figure 5: Concrete Block with Rebar

5.3.6 Summary of Results

The thickness of all sides of each concrete block was measured using the P-wave velocity obtained from the pitch-catch method of ultrasonic testing in conjunction with the resonance frequency. All results were within the specified tolerance of ±1 ft.

The compressive strength of the concrete blocks was measured by measuring the P-wave and S-wave time of travel with the pitch-catch method of ultrasonic testing. All results were within the specified tolerance of ±3 ksi.

The presence and approximate location of internal rebar was detected successfully using the pitch-catch method. When testing over a bar, the returned signal would increase greatly, indicating a strong reflection had occurred.

Metallic fibers were detected magnetically. It is not expected that metallic fibers will affect the ability to monitor and predict the other geometric and physical characteristics of the reinforced concrete structure. Synthetic fiber was not detected; however, higher frequency transducers might enable detection.

In considering the experimental data presented above, it is important to recognize that concrete compressive strength is not a constant throughout a structure, both spatially and temporally. Concrete is a highly non-homogenous material, and compressive strength can vary through the volume of a large concrete element. In a concrete structure comprised of many batches of concrete, strength will vary from batch to batch. Even in a relatively local area variations in strength may occur due to changes in placement, consolidation, and curing. In the case of a large cast-in-place wall, concrete will often be stronger towards the bottom because of more favorable curing conditions and the effect of the weight of the concrete from subsequent lifts consolidating the concrete below. This density effect is most noticeable in elements cast with many large lifts, but was detectable with the NLA RECON™ in the laboratory-scale concrete blocks (2’x3’x6’).

Temperature and moisture during curing will also cause local variations in concrete compressive strength. Concrete near the center of a mass concrete element (typically defined when a dimension is greater than 5 ft) is often stronger than concrete at the surfaces because the core concrete will experience higher temperatures and less moisture loss during curing. This effect is usually more pronounced with higher strength concretes that tend to generate more heat of hydration and have lower initial moisture contents. When dealing with high-strength concretes, cylinders can often under-predict the core concrete compressive strength of a mass concrete element. Concrete cylinder

compressive strengths tend to more closely reflect the surface properties of large concrete elements because the temperature and moisture conditions that the cylinders experience during curing are nearly the same as those experienced by the surfaces of a concrete element. For laboratory testing, cylinders are commonly cast and cured alongside the test specimens and hence, the concrete cylinder compressive strengths are likely less than that in the large concrete blocks tested in Phase I.

The NLA RECON™ determines the average concrete compressive strength through the entire thickness of the concrete element. In considering the test results reported herein, the NLA RECON™ tends to under-predict concrete compressive strengths for large concrete blocks, as compared to destructive cylinder test results. If this effect is deemed significant, core samples taken from the large concrete blocks can be taken and destructively tested to obtain a more accurate prediction of the actual concrete strength. In addition, the local variations in concrete material, due to regional differences, can also be taken into account when determining correction factors for concrete compressive strength.

5.3.7 Systematic Errors

Figure 6 shows the early part of the waveforms obtained from the two transducers in the P-wave velocity measurements. The travel time is measured as the time difference (Δt) between the two points at which the voltages rise above the background values. The maximum systematic error (e_p) in the calculated P-wave velocity, due to the differences between the measure travel time (Δt) and the true travel time (Δt'), is $e_p = \pm\delta t/\Delta t$ where δt is the sampling time of the data acquisition unit (0.2 µsec).

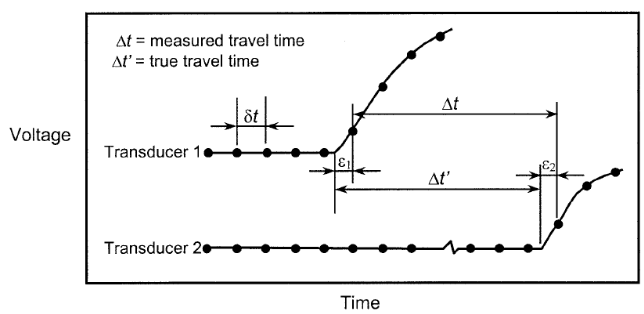


Figure 6: Early Part of the Waveforms from an Ultrasonic Pitch-Catch Test

Figure 7 shows the amplitude spectrum obtained from an impact-echo test. The high amplitude peak corresponds to the thickness frequency of the plate. The solid circles are the digital values displayed on the computer display, and the solid curve represents the true amplitude spectrum. The measured frequency (f) differs from the true frequency (f'). The maximum systematic error (e_f) in the calculated thickness due to the frequency interval in the amplitude spectrum is $e_f = \pm\Delta f/2f$ where Δf is the frequency interval that is controlled by the duration of the waveform (81 Hz).

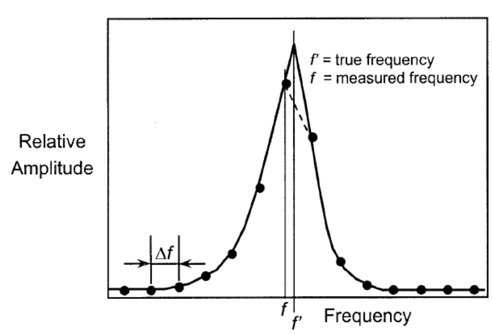


Figure 7: Amplitude Spectrum Resulting from an Impact-Echo Test

The thickness calculated from the P-wave speed and peak frequency includes two sources of systematic errors. The approach taken in this test method is to obtain the combined systematic error (e), as follows:

$$e = \sqrt{e_p^2 + e_f^2}$$

Therefore to account for the systematic error that is inherent in this test method, the thickness (T) is reported as T±Te and the calculations are shown in Table 6.

Table 6: Systematic Error in Thickness Test Method

Concrete Material	Actual T (ft)	T (ft)	Difference (ft)	δt (µs)	Δt (µs)	e_p	Δf (Hz)	e_f	e	Te (ft)
6 ksi	2	1.91	0.09	0.2	20	0.010	81	0.012	0.016	±0.030
	3	2.69	0.31	0.2	20	0.010	81	0.017	0.020	±0.054
	6	6.02	-0.02	0.2	20	0.010	81	0.039	0.040	±0.240
6 ksi + fiber	2	2.03	-0.03	0.2	19	0.011	81	0.012	0.016	±0.033
	3	2.81	0.19	0.2	19	0.011	81	0.017	0.020	±0.057
	6	6.28	-0.28	0.2	19	0.011	81	0.039	0.040	±0.251
12 ksi	2	1.81	0.19	0.2	21	0.010	81	0.012	0.015	±0.027
	3	2.65	0.35	0.2	21	0.010	81	0.017	0.020	±0.052
	6	5.93	0.07	0.2	21	0.010	81	0.039	0.040	±0.236
18 ksi	2	2.05	-0.05	0.2	19	0.011	81	0.012	0.016	±0.032
	3	2.82	0.18	0.2	19	0.011	81	0.016	0.019	±0.055
	6	6.42	-0.42	0.2	19	0.011	81	0.037	0.038	±0.246
UHPC	1	1.61	-0.61	0.2	15	0.013	81	0.009	0.016	±0.025
	2	1.92	0.08	0.2	15	0.013	81	0.010	0.017	±0.032
	1.5	1.99	-0.49	0.2	15	0.013	81	0.011	0.017	±0.034

6 Gantt Chart

Figure 8 represents the Gantt Chart that was updated throughout the period of performance.

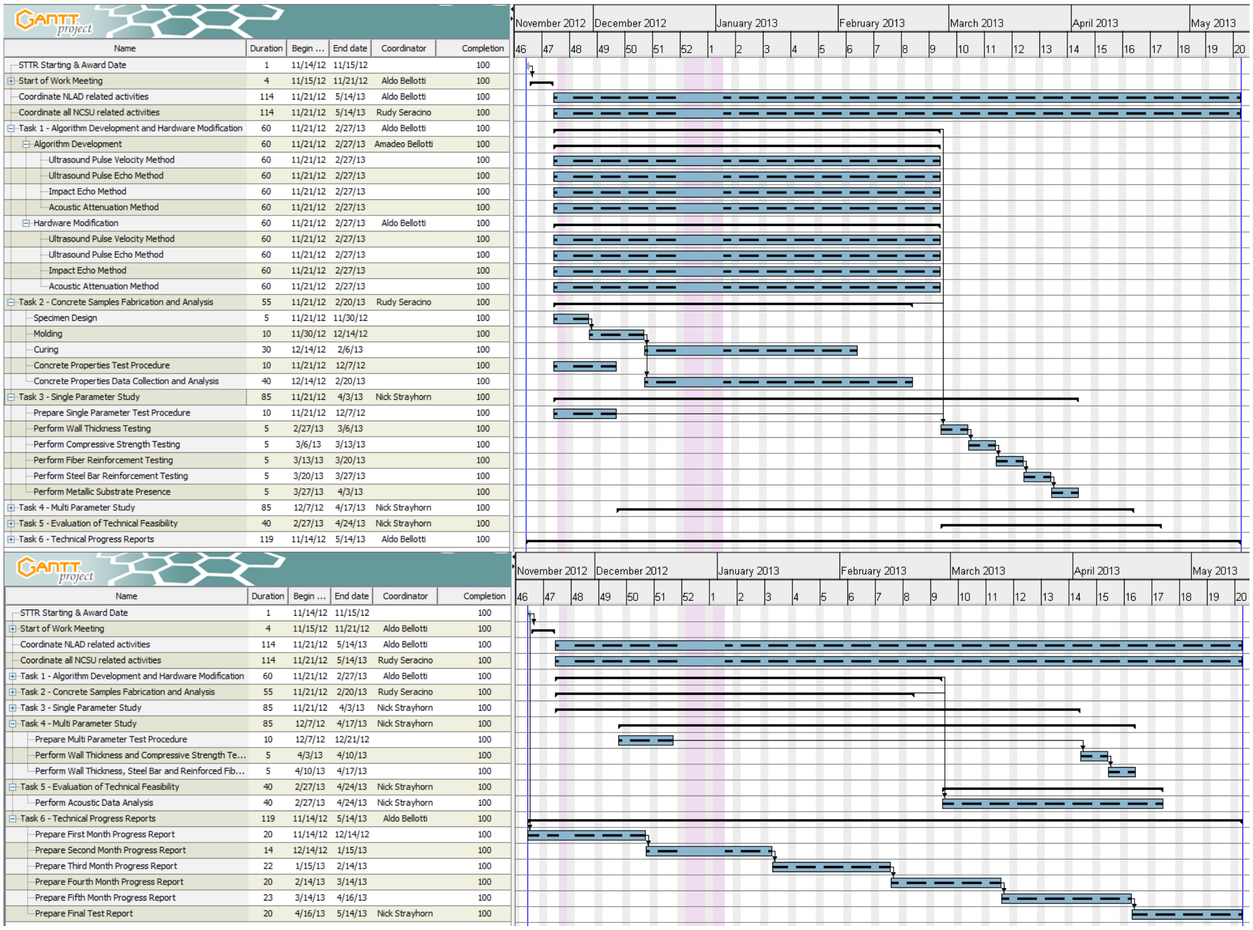


Figure 8: Gantt chart showing the schedule and critical path of Phase I tasks and activities

7 Acronyms

ADC	After Date of the Contract
ARO	Army Research Office
CFR	Code of Federal Regulations
CLIN	Contract Line Item Number
CME	Contractor Man-Year Equivalents
CMRA	Contractor Manpower Reporting Application
COR	Contracting Officer's Representative
COTR	Contracting Officer's Technical Representative
DFARS	Defense Federal Acquisition Regulation Supplement
DFAS	Defense Finance & Accounting Service (US DoD)
DoD	Department of Defense
DoDAAC	Department of Defense Activity Address Code
DTIC	Defense Technical Information Center
EAR	Export Administration Regulations
FAR	Federal Acquisition Regulation
FFP	Firm Fixed Price
FSC	Federal Service Code
FTR	Final Technical Report
IAW	In Accordance With
ITAR	International Traffic in Arms Regulations
KO	Contracting Officer
LPO	Local Processing Office
NLT	No Later Than
NTIS	National Technical Information Service
PI	Principal Investigator
SBA	Small Business Administration
SBC	Small Business Company
SOW	Statement OF Work
STTR	Small Business Technology Transfer
UIC	Unit Identification Code
WAWF	Wide Area WorkFlow